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VALUE ADDED ANALYSIS - VAAFY03

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13. ABSTRACT *(Maximum 200 Words)* This project was requested by the Office of the Deputy Chief of Staff, G8, Force Development. The purpose of the project was to evaluate the costs and benefits of selected weapon systems and to develop and evaluate alternative weapon system modernization programs. Value Added Analysis (VAA) analyzes benefits and costs among different weapon systems and munitions.				
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VALUE ADDED ANALYSIS - VAAFY03

SUMMARY

THE PROJECT PURPOSE was to evaluate the costs and benefits of selected weapon systems and to develop and evaluate alternative weapon systems modernization programs.

THE PROJECT SPONSOR is the Office of the Deputy Chief of Staff, G8 (DAPR-FDA), Headquarters, Department of the Army.

THE PROJECT OBJECTIVES were to:

(1) Determine the marginal effectiveness of selected modernization weapon systems.

(2) Determine the procurement costs of the modernized systems.

(3) Develop and analyze alternative weapon systems modernization programs.

THE SCOPE OF THE PROJECT: With Training and Doctrine Command (TRADOC) approved North East Asia (NEA) 3.0 scenario using Vector in Commander (VIC) corps level combat model, determine the effectiveness of modernized weapon systems as these systems compare to their base counterpart.

THE MAIN ASSUMPTIONS

(1) Combat simulations are an appropriate means of measuring weapon system combat effectiveness.

(2) The selected Measures of Effectiveness (MOE) adequately assessed the combined utility of the weapon systems under consideration.

(3) The TRADOC NEA scenario is appropriate to evaluate the weapon systems under consideration.

THE PRINCIPAL LIMITATIONS are**:**

(1) Not all procurement programs are analyzed because of the limitations of the corps combat model.

(2) Deployability, effects of training, and other readiness issues are not modeled.

(3) Cost Module does not include Operation and Maintenance Cost.

THE PRINCIPAL FINDINGS are**:**

(1) Paladin to Non-Line-of-Sight Cannon (NLOS-C): reflects positively with respect to overall Fractional Exchange Ratio (increases in blue killing ability and decreases in red killing ability).

(2) High Mobility Artillery Rocket System (HIMARS) performs significantly better than Multiple Launch Rocket System (MLRS) due to munitions. It too increases blue killing ability and reduces red killing ability.

(3) Joint Elevated Netted Sensors (JLENS) helps the Fractional Exchange Ratio and increases the amount of blue kills.

(4) Weather did not produce a measurable effect on the fight.

THE PROJECT EFFORT was conducted by LTC John Gregory Heck, Resource Analysis Division, Center for Army Analysis (CAA).

COMMENTS AND QUESTIONS may be sent to the Director, Center for Army Analysis, ATTN: CSCA-XX, 6001 Goethals Road, Suite 102, Fort Belvoir, VA 22060-5230

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1 INTRODUCTION

1.1 Value Added Analysis – VAAFY03

Headquarters, Department of the Army (HQDA), requires analysis to support the development of a balanced and effective modernization program. The Office of the Deputy Chief of Staff, G8, Force Development, requested this project. The purpose of the project is to identify and analyze marginal costs and benefits of weapon systems and develop feasible, affordable modernization investment strategies in support of defense reviews. In this case Value Added Analysis (VAA) was used in support of the Mini-POM (05-09). VAA analyzes benefits and costs among different weapon systems and munitions.

1.2 Background

In 2001 and 2002, two separate VAA studies were conducted for G8-FDA. The first used the South West Asia (SWA) 8.0 scenario and the second used the NEA 3.0 scenario. These two scenarios provided two totally different weather and terrain environments to assess the weapon system capabilities, adding validity and balance to the overall results. These simulation-modeling studies used the Vector in Commander (VIC) model (the Army's principal Corps-level simulation). VIC is a two-sided deterministic, discrete event simulation of combat in a combined arms environment representing land and air forces at the U.S. Army Corps level with a commensurate enemy force in a mid-intensity battle. The model has variable resolution, portrays non-linear warfare, represents all air land battle functions, and has been verified and validated by U.S. Army Training and Doctrine Command (TRADOC) schools and centers. The model is designed to provide a balanced representation of major force elements in a tactical campaign of a U.S. Army Corps operating in a Theater of Operations.

1.3 Purpose

The Value Added Analysis framework consists of the following modules: issue definition, effectiveness, cost, and optimization. The purpose of this effort is to generate and provide combat effectiveness data, cost estimate data, and using optimization formulation to determine investment strategies. The end result will be used as a tool in the analysis that goes into the decision making process for Program Objective Memorandum (POM) 05-09.

1.4 Key Assumptions

The key assumptions for VAAFY03 are:

(1) Combat simulations are an appropriate means of measuring weapon system combat effectiveness.
(2) The Measure of Effectiveness (MOE)(which is the Fractional Exchange Ratio – FER) properly depicts the effectiveness of each weapon system. We use Tanks, Anti-tank vehicles, Helicopters, and Artillery (TAHA) when determining the FER.

(3) The TRADOC NEA 3.0 scenario is appropriate to evaluate the weapon systems under consideration. The scenario properly stresses the systems being analyzed to show how effective the systems actually are.

1.5 Key Limitations

The key limitations for VAAFY03 are:

(1) Only one scenario and one timeframe are explicitly modeled.
(2) Not all procurement programs are analyzed because of a limitation of the corps combat model (Vector In Commander - VIC). VIC has a weakness in that it does not model Combat Support and Service Support well. The model focuses on the combat ability of systems. Because VIC is corps level, theater assets are not simulated well. This is evident when trying to simulate theater air defense systems – VIC is not a good tool to show the effectiveness of these systems.
(3) Deployability, effects of training, and other readiness issues are not modeled. Deployability is not modeled in VIC – the game turns on and the units are ready to fight (units can be delayed in entering the simulation, but once in – units are prepared to fight). The simulation is very sterile; all units with the same TOE have the same ability, all units ready to fight when simulation starts. VIC does not take training into account (Infantry Battalion A will be just as effective as Infantry Battalion B).
(4) Cost data is received from the Army Cost and Economic Analysis Center (CEAC). A shortcoming is that it does not provide O&M cost for all systems – dealing with new and future systems that do not have data to support the O&M cost. This is an issue we are attempting to fix.

1.6 Scope

The scope of this report includes the 15 weapon systems presented in Figure 1. The sponsor of the project, the Army G8, determined what Army weapon systems to include in VAAFY03. This report provides a comparison of the base systems as they compare to their modern counterparts.

Base Case	Ammunition	Near Term (2010)	Ammunition
MLRS (M270A1)	DPICM, Unitary	HIMARS	GMLRS, DPICM, Unitary
120mm Mortar	HE	120mm Mortar	HE, PGMM
		JLENS	
M1A2Sep		FCS MGS	
AH64D		RAH66	
		Shadow	
		Hunter	
M198	HE, DPICM	M777 LW 155	HE, DPICM, Excalibur
Paladin	HE, DPICM	NLOS-C	HE, DPICM, Excalibur
Weather		Weather	

Figure 1. Systems Considered

Also analyzed are the interactions between two systems. VAA identifies and analyzes all interactions between two systems. That interaction may include:

(1) Sensor and shooter.
(2) Direct and indirect fire systems.
(3) Two indirect fire systems.
(4) Two direct fire systems.

These interactions can be synergistic, anergistic, or negligible. Interactions between 3 or more weapon systems are not analyzed due to time and resource constraints.

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2 METHODOLOGY

2.1 VAA Methodology

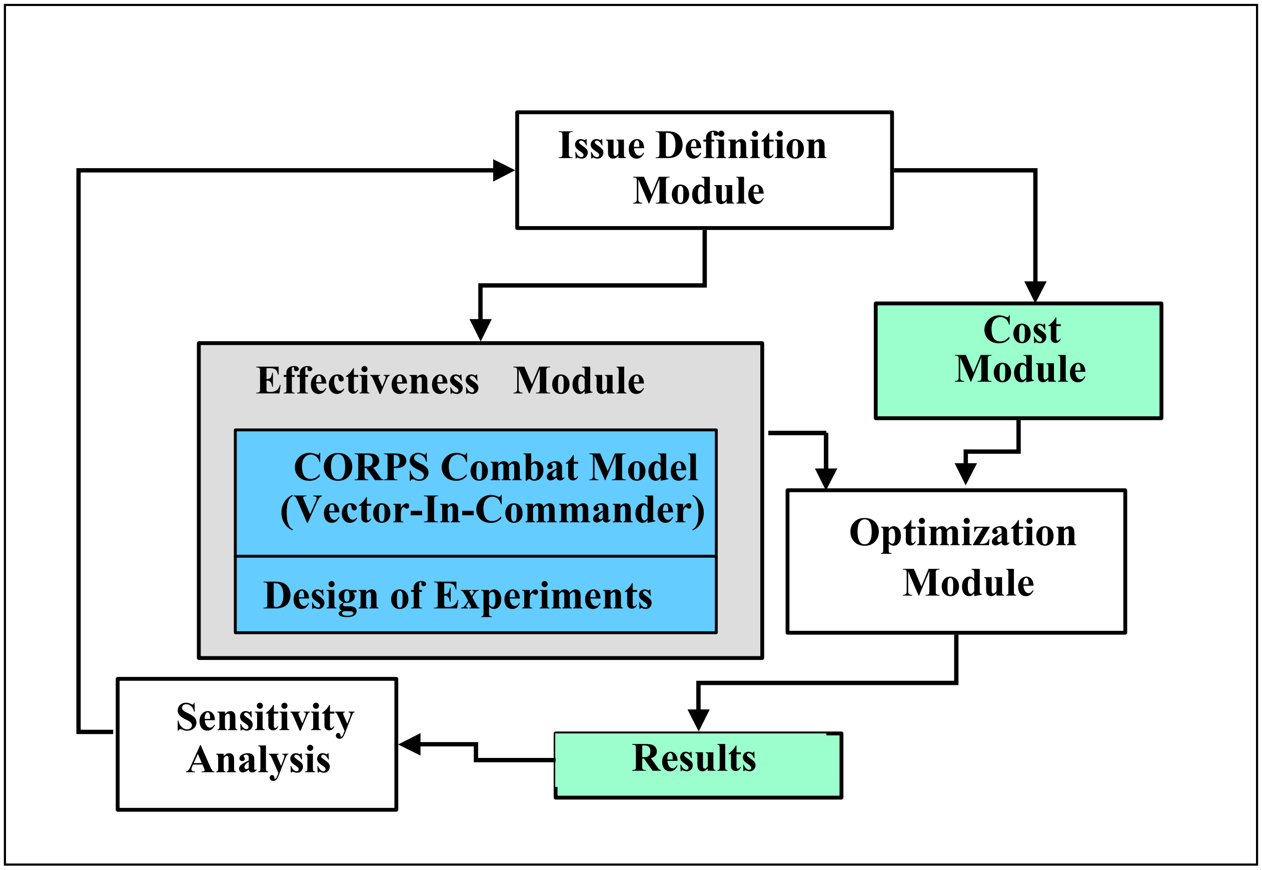
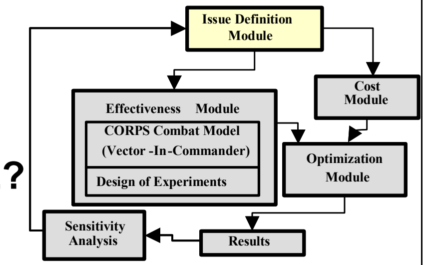


Figure 2. VAA Methodology

Figure 2 provides the framework of the Value Added Analysis (VAA) methodology. The VAA methodology was developed in the late 1980s to address the problem of cross mission area tradeoffs between modernization programs. It consists of a series of sub-analyses integrated into a methodology that culminates in the generation of recommended acquisition strategies. The conduct of a VAA study typically consists of an initial long-term project followed by a series of quick reaction analyses. The long-term project is designed to develop the cost and effectiveness information necessary to support the analysis of the issues in the current Program Objective Memorandum (POM) decision cycle. The follow-on quick reaction analyses then address specific questions and concerns. This report will discuss the long-term portion of the analysis.

2.2 Issue Definition Module

- What are the cost and benefits of the...
  - Comanche compared to the Apache?
  - NLOS compared to the Paladin?
  - HIMARS compared to the MLRS?
  - 120mm PGMM compared to 120mm HE?
  - FCS MCS compared to the M1A2Sep?
  - M777 compared to the M198?
  - Shadow 200 UAV?
  - Hunter UAV?



- What is the effect of limited visibility (good weather/bad weather) in the NEA scenario on the systems and the measures of effectiveness?
- What are the synergies between systems in the NEA scenario?
- What are some good system investment strategies based upon the NEA scenario?

Figure 3. Issue Definition Module

The VAA procedure begins with the determination of the systems to be addressed in the current iteration of VAA. This list is developed in conjunction with the study sponsor. Figure 3 addresses questions that the sponsor requested to be analyzed. The issue definition module requires that the problem be defined and its associated elements be studied so that the data collection and analysis efforts can be focused upon the questions and issues of interest to decision makers. The general context of the study in terms of systems and programs to be analyzed is established, along with timeframes and scenarios of interest.

Figure 1 provides the list of systems and munitions that were analyzed.

2.3 Effectiveness Module

Using Vector-In-Commander (VIC) as the corps-level combat simulation, the relative contribution of systems to combat effectiveness is determined.

Using experimental design techniques, data is collected from the simulation runs and the contribution of each of the evaluated systems to the measures of effectiveness is calculated.

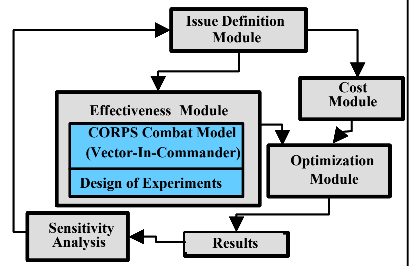


Figure 4. Effectiveness Module

The purpose of this effort is to generate and provide combat effectiveness data for input into the VAA process. The modeling and analysis effort for the effectiveness module uses the Vector In Commander (VIC) model with a TRADOC approved North East Asia (NEA) scenario in a balanced 64 run design of experiment to calculate loss and force exchange ratios. These ratios form the main inputs into the effectiveness module of the VAA process.

The effectiveness module is the most time/resource intensive module in the analytical framework. The end result of this portion of the process is to generate the objective function for the mixed integer optimization program in the final section of the methodology. The first step in this module is to determine the design of experiment. The design of experiment was built to address the need to support a hypothesized set of predictor variables.

The run matrix of the design of experiment was created to support analysis of the ten treatment factors, named Mortar, Helo, Tank, Rkt Arty, SP Arty, Towed Arty, Shadow, Hunter, JLENS, and Weather in the context of least squares regression analysis. This regression model in generic form is:

$$y_i = \alpha + \sum_{j=1}^{m} \beta_j x_{ij} + \varepsilon_i$$

where *i* represents the observation number. The ε_i are modeled as statistically independent of the x's and each other, and randomly distributed according to a normal distribution with mean zero and variance σ^2. Under these assumptions, the regression coefficients are to be taken as unbiased indications of the effect of different equipment trades, but they are subject to estimation error due to sampling.

The design matrix (Figure 5) is a fractional factorial design, in which all combinations of six factors define the 64 runs, and the remaining four factors are obtained by multiplying various combinations of the six factors. The design matrix is balanced with respect to the hypothesized effects, and none of these hypothesized interaction effects are confounded or aliased. The matrix is chosen so that any two of the variables or products in the equation are uncorrelated and have a mean of zero. For example, if one forms the products of $JLENS_i$ with $HIMARS_i*Hunter_i$ their sum will be zero over the experimental design. A consequence of this lack of correlation is that, for each of the levels of term A, the average value of term B is zero. This implies that MOE differences between the levels of A as seen in the raw data are unaffected by the value taken by the coefficient for any term, B. Because of this property, difference in the means of treatment groups are not misleading in view of the other treatment effects or interactions as long as these are among the hypothesized set. The regression coefficients will be exactly one-half of the observed differences.

The notion of VIC output measures being random deserves comment in view of the deterministic nature of VIC. VIC is a two-sided, deterministic, discrete-event simulation of combat in a combined arms environment representing land and air forces at the U.S. Army Corps level with a commensurate enemy force in a mid-intensity battle. The model is variable resolution, portrays non-linear warfare, represents all air land battle functions, and has been verified and validated by TRADOC schools and centers. The model is designed to provide a balanced representation of major force elements in a tactical campaign of a U.S. Army Corps operating in a Theater of Operations.

01	MTR w/o PGMM	AH64D	M1A2 SEP	MLRS	Paladin	M198	none	None	JLENS	Bad Weather
02	MTR w/o PGMM	AH64D	M1A2 SEP	MLRS	Paladin	M198	Shadow	None	null	Bad Weather
03	MTR w/o PGMM	AH64D	M1A2 SEP	MLRS	NLOS-C	M198	none	None	null	Good Weather
04	MTR w/o PGMM	AH64D	M1A2 SEP	MLRS	NLOS-C	M198	Shadow	None	JLENS	Good Weather
05	MTR w/o PGMM	AH64D	M1A2 SEP	HIMARS	Paladin	M777	none	None	JLENS	Good Weather
06	MTR w/o PGMM	AH64D	M1A2 SEP	HIMARS	Paladin	M777	Shadow	None	null	Good Weather
07	MTR w/o PGMM	AH64D	M1A2 SEP	HIMARS	NLOS-C	M777	none	None	null	Bad Weather
08	MTR w/o PGMM	AH64D	M1A2 SEP	HIMARS	NLOS-C	M777	Shadow	None	JLENS	Bad Weather
09	MTR w/o PGMM	AH64D	FCS MGS	MLRS	Paladin	M777	none	Hunter	null	Good Weather
10	MTR w/o PGMM	AH64D	FCS MGS	MLRS	Paladin	M777	Shadow	Hunter	JLENS	Good Weather
11	MTR w/o PGMM	AH64D	FCS MGS	MLRS	NLOS-C	M777	none	Hunter	JLENS	Bad Weather
12	MTR w/o PGMM	AH64D	FCS MGS	MLRS	NLOS-C	M777	Shadow	Hunter	null	Bad Weather
13	MTR w/o PGMM	AH64D	FCS MGS	HIMARS	Paladin	M198	none	Hunter	null	Bad Weather
14	MTR w/o PGMM	AH64D	FCS MGS	HIMARS	Paladin	M198	Shadow	Hunter	JLENS	Bad Weather
15	MTR w/o PGMM	AH64D	FCS MGS	HIMARS	NLOS-C	M198	none	Hunter	JLENS	Good Weather
16	MTR w/o PGMM	AH64D	FCS MGS	HIMARS	NLOS-C	M198	Shadow	Hunter	null	Good Weather
17	MTR w/o PGMM	RAH66	M1A2 SEP	MLRS	Paladin	M777	none	Hunter	null	Good Weather
18	MTR w/o PGMM	RAH66	M1A2 SEP	MLRS	Paladin	M777	Shadow	Hunter	JLENS	Good Weather
19	MTR w/o PGMM	RAH66	M1A2 SEP	MLRS	NLOS-C	M777	none	Hunter	JLENS	Bad Weather
20	MTR w/o PGMM	RAH66	M1A2 SEP	MLRS	NLOS-C	M777	Shadow	Hunter	null	Bad Weather
21	MTR w/o PGMM	RAH66	M1A2 SEP	HIMARS	Paladin	M198	none	Hunter	null	Bad Weather
22	MTR w/o PGMM	RAH66	M1A2 SEP	HIMARS	Paladin	M198	Shadow	Hunter	JLENS	Bad Weather
23	MTR w/o PGMM	RAH66	M1A2 SEP	HIMARS	NLOS-C	M198	none	Hunter	JLENS	Good Weather
24	MTR w/o PGMM	RAH66	M1A2 SEP	HIMARS	NLOS-C	M198	Shadow	Hunter	null	Good Weather
25	MTR w/o PGMM	RAH66	FCS MGS	MLRS	Paladin	M198	none	None	JLENS	Bad Weather
26	MTR w/o PGMM	RAH66	FCS MGS	MLRS	Paladin	M198	Shadow	None	null	Bad Weather
27	MTR w/o PGMM	RAH66	FCS MGS	MLRS	NLOS-C	M198	none	None	null	Good Weather
28	MTR w/o PGMM	RAH66	FCS MGS	MLRS	NLOS-C	M198	Shadow	None	JLENS	Good Weather
29	MTR w/o PGMM	RAH66	FCS MGS	HIMARS	Paladin	M777	none	None	JLENS	Good Weather
30	MTR w/o PGMM	RAH66	FCS MGS	HIMARS	Paladin	M777	Shadow	None	null	Good Weather
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32	MTR w/o PGMM	RAH66	FCS MGS	HIMARS	NLOS-C	M777	Shadow	None	JLENS	Bad Weather
33	MTR w/ PGMM	AH64D	M1A2 SEP	MLRS	Paladin	M198	none	Hunter	JLENS	Bad Weather
34	MTR w/ PGMM	AH64D	M1A2 SEP	MLRS	Paladin	M198	Shadow	Hunter	null	Bad Weather
35	MTR w/ PGMM	AH64D	M1A2 SEP	MLRS	NLOS-C	M198	none	Hunter	null	Good Weather
36	MTR w/ PGMM	AH64D	M1A2 SEP	MLRS	NLOS-C	M198	Shadow	Hunter	JLENS	Good Weather
37	MTR w/ PGMM	AH64D	M1A2 SEP	HIMARS	Paladin	M777	none	Hunter	JLENS	Good Weather
38	MTR w/ PGMM	AH64D	M1A2 SEP	HIMARS	Paladin	M777	Shadow	Hunter	null	Good Weather
39	MTR w/ PGMM	AH64D	M1A2 SEP	HIMARS	NLOS-C	M777	none	Hunter	null	Bad Weather
40	MTR w/ PGMM	AH64D	M1A2 SEP	HIMARS	NLOS-C	M777	Shadow	Hunter	JLENS	Bad Weather
41	MTR w/ PGMM	AH64D	FCS MGS	MLRS	Paladin	M777	none	None	null	Good Weather
42	MTR w/ PGMM	AH64D	FCS MGS	MLRS	Paladin	M777	Shadow	None	JLENS	Good Weather
43	MTR w/ PGMM	AH64D	FCS MGS	MLRS	NLOS-C	M777	none	None	JLENS	Bad Weather
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47	MTR w/ PGMM	AH64D	FCS MGS	HIMARS	NLOS-C	M198	none	None	JLENS	Good Weather
48	MTR w/ PGMM	AH64D	FCS MGS	HIMARS	NLOS-C	M198	Shadow	None	null	Good Weather
49	MTR w/ PGMM	RAH66	M1A2 SEP	MLRS	Paladin	M777	none	None	null	Good Weather
50	MTR w/ PGMM	RAH66	M1A2 SEP	MLRS	Paladin	M777	Shadow	None	JLENS	Good Weather
51	MTR w/ PGMM	RAH66	M1A2 SEP	MLRS	NLOS-C	M777	none	None	JLENS	Bad Weather
52	MTR w/ PGMM	RAH66	M1A2 SEP	MLRS	NLOS-C	M777	Shadow	None	null	Bad Weather
53	MTR w/ PGMM	RAH66	M1A2 SEP	HIMARS	Paladin	M198	none	None	null	Bad Weather
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56	MTR w/ PGMM	RAH66	M1A2 SEP	HIMARS	NLOS-C	M198	Shadow	None	null	Good Weather
57	MTR w/ PGMM	RAH66	FCS MGS	MLRS	Paladin	M198	none	Hunter	JLENS	Bad Weather
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60	MTR w/ PGMM	RAH66	FCS MGS	MLRS	NLOS-C	M198	Shadow	Hunter	JLENS	Good Weather
61	MTR w/ PGMM	RAH66	FCS MGS	HIMARS	Paladin	M777	none	Hunter	JLENS	Good Weather
62	MTR w/ PGMM	RAH66	FCS MGS	HIMARS	Paladin	M777	Shadow	Hunter	null	Good Weather
63	MTR w/ PGMM	RAH66	FCS MGS	HIMARS	NLOS-C	M777	none	Hunter	null	Bad Weather
64	MTR w/ PGMM	RAH66	FCS BLOS	HIMARS	NLOS-C	M777	Shadow	Hunter	JLENS	Bad

Figure 5. Design of Experiment

The design of experiment (DOE) was built to address the need to support a hypothesized set of predictor variables in regression models of scenario MOE. The DOE needed to support analysis of the treatment of effects – in this analysis we coded the treatment conditions with numeric values of –1 and +1 as follows (Figure 6):

	Coding	**Coding**
Effect	**-1**	**1**
Mortar	M121 Mortar	M121 Mortar w/ PGMM
Helo	AH64D	RAH66
Tank	M1A2 SEP	FCS MGS
Rkt Arty	MLRS	HIMARS
SP Arty	Paladin	NLOS-C
Towed Arty	M198	M777
Shadow	Null	Shadow
Hunter	Null	Hunter
JLENS	Null	JLENS
Weather	Good	Bad

Figure 6. DOE Coding

Coded this way, a regression coefficient equates to half of the difference to be expected from a given trade. In addition to supporting the analysis of the differences attributable to these effects, the design of experiments also needed to have more runs added to support the use of certain statistical methods.

Finally, analysis by subject matter experts suggested that synergies between combat systems would imply the existence of regression model interaction effects, in which the effect of trade A differs according to the level of factor B, for some A and B. The interaction effects thus hypothesized are presented in Figure 7 below:

Factor	**Mortar**	**Helo**	**Tank**	**Rkt Arty**	**SP Arty**	**Towed Ar**	**Shadow**	**Hunter**	**JLENS**	**Weather**
Mortar										
Helo			X	X	X	X				X
Tank										X
Rkt Arty								X	X	
SP Arty							X	X	X	
Towed Arty							X		X	
Shadow										
Hunter										
JLENS										
Weather										

Figure 7. Hypothesized Interactions

The hypothesized family of regression models is thus

$Y_i = \alpha + \beta_1*Mortar_i + \beta_2*Helo_i + \beta_3*Tank_i + \beta_4*M270_i + \beta_5*SP\_Arty_i + \beta_6*Towed\_Arty_i + \beta_7*Shadow_i + \beta_8*Hunter_i + \beta_9*JLENS_i + \beta_{10}*Weather_i + \beta_{23}*Helo_i*Tank_i + \beta_{24}*Helo_i*M270_i + \beta_{25}*Helo_i*SP\_Arty_i + \beta_{26}*Helo_i*Towed\_Arty_i + \beta_{2,10}*Helo_i*Weather_i + \beta_{3,10}Tank*Weather + \beta_{48}*M270_i*Hunter_i + \beta_{49}*M270_i*JLENS_i + \beta_{57}*SP\_Arty_i*Shadow_i + \beta_{58}*SP\_Arty_i*Hunter_i + \beta_{59}*SP\_Arty_i*JLENS_i + \beta_{67}*Towed\_Arty_i*Shadow_i + \beta_{69}*Towed\_Arty_i*JLENS_i + \varepsilon_i$

where i is the run number and Y_i is an MOE or component.

- **Conduct base case runs to obtain consistent MOEs.**
- **Conduct switch analysis runs to test "value added" effect of new weapon systems.**
  - **One at at a time replacement for all systems.**
  - **Modify technical and operational data sets so the scenario results are credible.**
- **Conduct demonstration case runs IAW experimental design.**
  - **64 runs – combination of base systems and modern systems.**
  - **Modify technical and operational data sets so the scenario results are credible.**
  - **Identify ammunition contribution to system effectiveness.**

Figure 8. Design Methodology

The design methodology used for the effectiveness module is listed in Figure 8. A two-step process was used as it pertained to VIC runs.

Step one was to conduct the base case runs. After we were comfortable with the base runs (flow of the battle with the base systems) we conducted switch analysis. A modern system was substituted for a base system in VIC to determine if the data for the modern system enabled the system to perform as one would expect it to perform. This was done for each modernized system. Analysis was conducted on each of these runs to ensure the modernized systems performed as one would expect. If there were any questions reference the performance of the modernized system more analysis was conducted to determine if there were flaws in any of the

data. Once we were satisfied with the base case/switch analysis, we then conducted the design of experiment (DOE) runs.

Shown in Figure 9 are the Loss Exchange Ratios (LER's) and Fractional Exchange Ratios (FER's) that resulted from the 64 DOE runs with all equipment types equally weighted. LER is the ratio of Red losses compared to Blue losses. FER is an indication of the likelihood that the Blue force wins or loses by measuring the fractional Red losses compared to fractional Blue losses, normalized for the size of each force. The data used in the LER/FER calculation was computed from the model's record of killer-victim interactions (the “Record 1” file from VIC output). These files were filtered in a controlled and auditable manner using the “SAS” statistical package. Thus the LER and FER were calculated directly from source data using an automated filtering mechanism.

Run	RED Losses	BLUE Losses	LER	RED initial	BLUE initial	RED Losses / RED initial	BLUE Losses / BLUE initial	FER
1	1060	885	1.20	2872	1656	0.37	0.53	0.69
2	1130	948	1.19	2872	1656	0.39	0.57	0.69
3	1493	613	2.44	2872	1656	0.52	0.37	1.40
4	1458	683	2.13	2872	1656	0.51	0.41	1.23
5	1320	654	2.02	2872	1656	0.46	0.39	1.16
6	1240	614	2.02	2872	1656	0.43	0.37	1.16
7	1546	656	2.36	2872	1656	0.54	0.40	1.36
8	1600	524	3.05	2872	1656	0.56	0.32	1.76
9	1144	833	1.37	2872	1656	0.40	0.50	0.79
10	1307	808	1.62	2872	1656	0.46	0.49	0.93
11	1529	805	1.90	2872	1656	0.53	0.49	1.10
12	1221	645	1.89	2872	1656	0.43	0.39	1.09
13	1283	706	1.82	2872	1656	0.45	0.43	1.05
14	1442	639	2.26	2872	1656	0.50	0.39	1.30
15	1647	672	2.45	2872	1656	0.57	0.41	1.41
16	1581	460	3.44	2872	1656	0.55	0.28	1.98
17	1154	854	1.35	2872	1656	0.40	0.52	0.78
18	1270	788	1.61	2872	1656	0.44	0.48	0.93
19	1526	681	2.24	2872	1656	0.53	0.41	1.29
20	1382	636	2.17	2872	1656	0.48	0.38	1.25
21	1205	759	1.59	2872	1656	0.42	0.46	0.92
22	1436	684	2.10	2872	1656	0.50	0.41	1.21
23	1845	466	3.96	2872	1656	0.64	0.28	2.28
24	1562	530	2.95	2872	1656	0.54	0.32	1.70
25	1162	815	1.43	2872	1656	0.40	0.49	0.82
26	1168	837	1.40	2872	1656	0.41	0.51	0.80
27	1281	726	1.76	2872	1656	0.45	0.44	1.02
28	1487	666	2.23	2872	1656	0.52	0.40	1.29
29	1418	693	2.05	2872	1656	0.49	0.42	1.18
30	1152	714	1.61	2872	1656	0.40	0.43	0.93
31	1358	597	2.27	2872	1656	0.47	0.36	1.31
32	1530	673	2.27	2872	1656	0.53	0.41	1.31
33	1303	689	1.89	2872	1656	0.45	0.42	1.09
34	1264	656	1.93	2872	1656	0.44	0.40	1.11
35	1355	639	2.12	2872	1656	0.47	0.39	1.22
36	1451	618	2.35	2872	1656	0.51	0.37	1.35
37	1535	615	2.50	2872	1656	0.53	0.37	1.44
38	1344	686	1.96	2872	1656	0.47	0.41	1.13
39	1487	570	2.61	2872	1656	0.52	0.34	1.50
40	1717	701	2.45	2872	1656	0.60	0.42	1.41
41	1150	796	1.44	2872	1656	0.40	0.48	0.83
42	1323	709	1.87	2872	1656	0.46	0.43	1.08
43	1450	610	2.38	2872	1656	0.50	0.37	1.37
44	1236	696	1.78	2872	1656	0.43	0.42	1.02
45	1560	575	2.71	2872	1656	0.54	0.35	1.56
46	1544	736	2.10	2872	1656	0.54	0.44	1.21
47	1669	509	3.28	2872	1656	0.58	0.31	1.89
48	1428	643	2.22	2872	1656	0.50	0.39	1.28
49	1213	888	1.37	2872	1656	0.42	0.54	0.79
50	1328	874	1.52	2872	1656	0.46	0.53	0.88
51	1535	537	2.86	2872	1656	0.53	0.32	1.65
52	1367	631	2.17	2872	1656	0.48	0.38	1.25
53	1081	741	1.46	2872	1656	0.38	0.45	0.84
54	1578	762	2.07	2872	1656	0.55	0.46	1.19
55	1513	700	2.16	2872	1656	0.53	0.42	1.25
56	1430	579	2.47	2872	1656	0.50	0.35	1.42
57	1400	851	1.65	2872	1656	0.49	0.51	0.95
58	1352	656	2.06	2872	1656	0.47	0.40	1.19
59	1432	591	2.42	2872	1656	0.50	0.36	1.40
60	1483	809	1.83	2872	1656	0.52	0.49	1.06
61	1516	618	2.45	2872	1656	0.53	0.37	1.41
62	1325	777	1.71	2872	1656	0.46	0.47	0.98
63	1487	634	2.35	2872	1656	0.52	0.38	1.35
64	1713	484	3.54	2872	1656	0.60	0.29	2.04
ave	**1399**	**685**	**2.122**	**2872**	**1656**	**0.487**	**0.414**	**1.223**

Figure 9. FER and LER

What was modeled: the DOE is made up of ten factors. Six of those factors were shooters, three were sensors, and the last was weather. After pruning the set of interaction effects that could be accommodated by the design of experiments to a workable level, a fractional factorial design was found that would accommodate the desired model. The final DOE was efficient in that it maintained the desired interaction or main effects separate from other effects in the design.

Despite a significant effort to anticipate interaction effects (based on previous experience with the scenario used), and the resultant engineering of the DOE with this in mind, the resulting output data contained only one interaction that had effects of statistical significance. Hence, statistical analyses to confirm or identify treatment differences were performed using regression without interaction effects (except for the one positive interaction).

Summary of VIC results: The primary effects registered from this DOE can be quickly gleaned from Figure 10. The Green boxes indicate those cells that are "statistically significant" which is a mathematical way of saying the effect can't be attributed to random chance alone.

The first green column is Self Propelled Artillery (Paladin to NLOS-C) and the reader can see that the change to this system (not the performance of either system but the delta between them) reflects positively with respect to the overall LER which is to say it helps the LER, positively with respect to "Side 1 kills" which is to say it increases kills by blue; and negatively with respect to "Side 2 kills" which is to say it reduces kills by red.

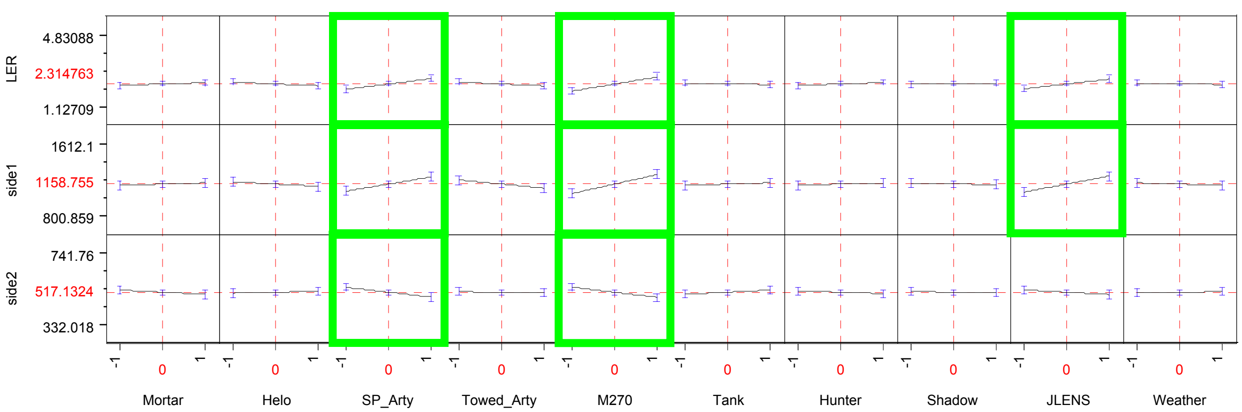

Figure 10. Primary Effects

The second green column is the Rocket Artillery (MLRS to HIMARS) and we can make an identical statement here as well - that the Rocket Artillery helps the LER, increase kills by blue and reduce kills by red. The final system to display statistically significant results is JLENS. The reader finds that the presence of JLENS helps the LER, and increases kills by blue. Those are pretty broad sweeping statements to make from the presence of a sensor, but due to the uncorrelated nature of our experimental design we can make them with a high degree of certainty.

These results are not intended to communicate that these systems are the primary killers on the battlefield. This may be the case, but is not necessarily so. It bears repeating that we are viewing those deltas or differences between the base system and its modified partner that yield significant results. If the base system is already performing well, then the modified system will be hard pressed to register an improvement.

The sponsor requested that we look at the capability of weapon systems as it pertains to its performance in various weather conditions (good and poor). In order for Weather to cause a statistical difference to Blue kills, it would have to reduce Blue systems effectiveness to a large degree (something we wouldn't anticipate) or possibly it would have to change the tactical situation so much that Blue could shoot and kill in an unusually effective manner. This might be possible if maneuverability was modeled in detail and drastically affected Red systems. What would it take for Weather to register a statistical difference on Red kills? If Red systems were extremely ineffective (relative to Blue) at killing in poor visibility, and if that were represented to a significant degree in the model, we could register a difference there. As it turns out, a change in Weather did not produce a measurable effect on the outcome of the fight (FER). This is not to say that Weather didn't produce an effect on the fight. It certainly changed the dynamics of the battle.

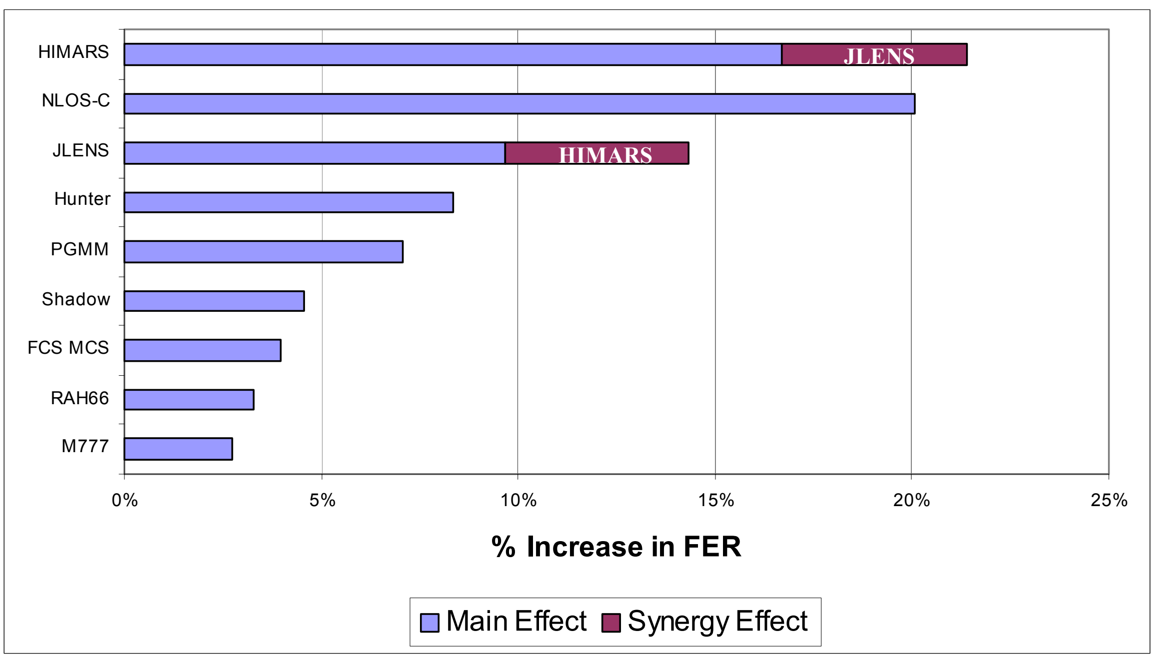

Figure 11. Increase in the Fractional Exchange Ratio

After completion of the DOE runs, analysis was conducted to determine the fractional exchange ratio for each run. Regression analysis was then conducted on each run to determine the percent increase for each modern system. Figure 11 represents the percent increase as it pertains to the fractional exchange ratio for the modern systems compared to the base systems.

Also shown is the significant synergy effect between systems. There was only one interaction that had a significant effect – HIMARS and JLENS. The percent increase in the fractional exchange ratio for this synergy is shown in Figure 11.

2.4 Cost Module

- **Costs are estimated using the most accurate data available from the Army Cost and Economic Analysis Center (CEAC).**
- **Costs included:**
  - **Research, development, test, and evaluation (RDT&E) costs.**
  - **Fixed production costs.**
  - **Variable production costs, to include learning curve effects.**
- **The annual RDA appropriation is estimated from a base planning document and used to constrain procurement expenditures for a given year.**

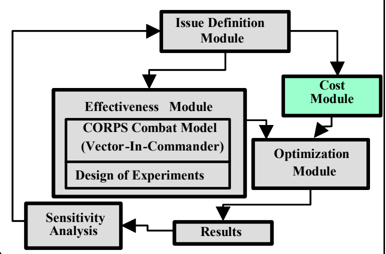

Figure 12. Cost Module

The purpose for the cost module is twofold. First, accurate system procurement costs must be estimated, including research, development, test and evaluation (RDT&E) costs; fixed production costs; and variable production costs. These costs are necessary for conducting the optimization that finds the mix of systems that maximizes the effectiveness of the force subject to constraints on the Research, Development, and Acquisition (RDA) budget. Second, given optimization quantities of procured systems, estimates must be computed of the other aspects of the life cycle costs of the system. These aspects include fielding costs, containment costs, and

facilities costs. Once the various components of the life cycle costs are computed, they must be made available in an easily accessible form so that information regarding the costs of the modern systems can be analyzed.

An important aspect of estimating the procurement costs associated with the modern systems is determining whether or not a significant relationship exists between the unit cost of a system and the quantity procured. For many of the modern systems, particularly the developmental systems that involve new technology (such as the FCS systems), this cost-quantity relation is significant and nonlinear. As such, this relationship must be considered and accounted for to ensure accurate results. For the purposes of this study, the cost-quantity relationship reflects economies of scale in terms of materials and labor, as well as "learning" on the part of production labor force. The Army Cost and Economic Analysis Center generated the cost data that included the following:

1.0 - Total RDT&E by year cost in same year constant dollar;
2.0 - By year cost in same year constant dollar spread by year for each
sub-element (2.01 to 2.14) production quantity by year; and,
5.0 - Total OMA by year cost in same year constant dollar, and breakout
by:
 * 5.03 - Consumables
 * 5.04 - Reparables
 * 5.05 - POL

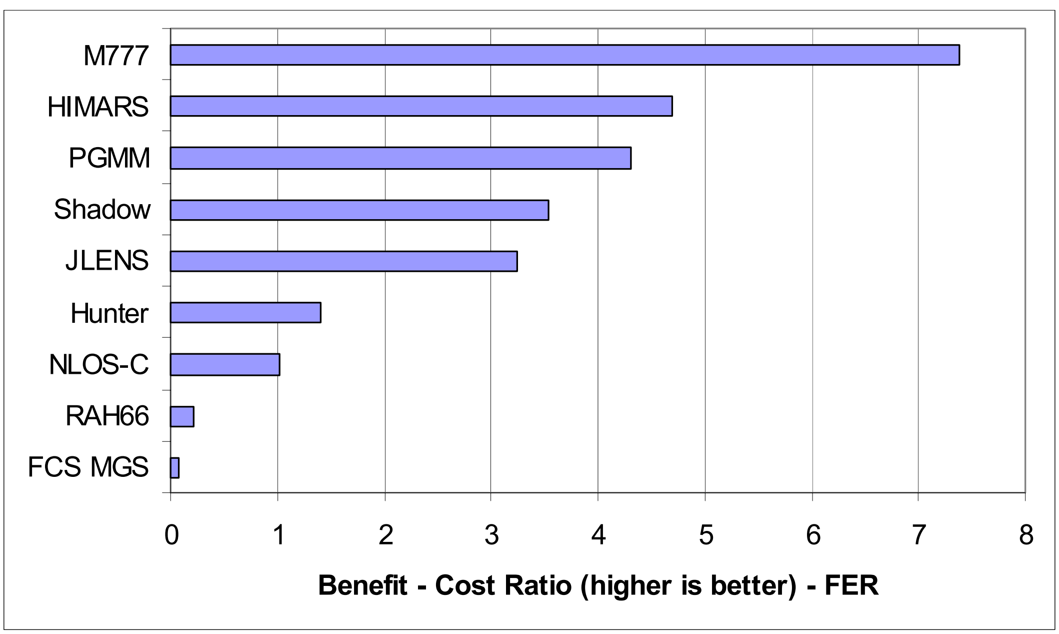

Figure 13. Benefit-Cost Ratio

Cost estimates are completed for each modern system. The effectiveness per system (percent increase in FER) is then divided by the cost per system to determine the "Benefit-Cost Ratio". Figure 13 depicts the "Benefit-Cost Ratio" for this study. The phrase "Most Bang for the Buck" is often used for this outcome. It was determined that the M777 provided the "Most Bang for the Buck" for this scenario. One must understand that the results are for a certain scenario and may change in a different setting/scenario.

2.5 Optimization Module

- **System effectiveness and costs are inputs for a mathematical optimization model that develops affordable, feasible program alternatives of what systems to buy, when to buy them, and how many to buy.**

- **The results are affordable because production limitations and budget constraints are met.**

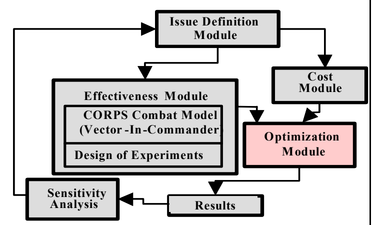

Figure 14. Optimization Module

The optimization module generates several acquisition strategies for the systems under consideration. This acquisition strategy is obtained from a mixed integer, linear programming optimization model, with the objective of maximizing the total effectiveness of the Army, as generated in the effectiveness module discussed earlier. This objective is constrained to meet the requirements of staying within the total obligation authority allocated to the systems under consideration, meeting the fielding goals obtained from the Army G8, staying within the ability of the production lines to produce the equipment, and finally taking any industrial base concerns into consideration.

There are several variables that are fed into the optimization module. The following provides the variables with definition:

Fixed Costs: Any cost that is incurred by a program that is not related to the quantity of the item produced is designated a fixed cost. The model considers two such categories of cost. The first is Research, Development, Test, and Evaluation (RDTE) costs. These costs are typically incurred during the POM period, and, as the name implies, pay for many of the developmental aspects of the procurement programs. The other category is that of fixed production costs. These costs are incurred just prior to, and early in the production phase of the funding profile for the programs. These costs are incurred irrespective of the quantity produced. Any line closing costs at the conclusion of the production of the program are also represented as fixed costs. All of the fixed costs are summed for each year and are assessed against the program if the program is selected for funding.

Variable Production Costs: The costs associated with the production of an individual item are designated as variable costs. These costs are also represented in two ways. The first concerns items for which there is no change in the cost as a function of the quantity produced. This means there is no learning behavior that is identifiable in the per-unit of the item for the entire cost, or for some component of the cost. In this case, an average unit cost is given and is assessed for each item produced. The second concerns items that do exhibit an identifiable learning behavior in their variable costs.

Force Structure Requirements: Force structure requirements drive the decisions regarding how many of a particular item of equipment should be procured. For each candidate program, the study sponsor must specify the level of force structure that is to be modernized with the candidate system. The specification might be in terms of force packages to be modernized, in terms of some other grouping of units, or as a total number of items to be procured. Often the sponsor will specify the exact program with respect to the years of procurement and the yearly procurement quantities. The optimization model is flexible enough to handle any of these methods of specifying total required quantities for the candidate systems.

Production Limitations: An important aspect of the VAA methodology is the computation of a feasible acquisition strategy for each of the funded candidate/modernized systems. To ensure feasibility, the ability of industry to produce the specified quantity in each year of the production campaign of each funded program is accounted. Thus, the yearly production quantities must be constrained to be between the minimum sustaining rate of production and the maximum production rate of production. These values which are provided as data represent the output of one 8-hour shift and three 8-hour shifts, respectively, of the specified production facility for the given candidate system. Additionally, initial quantities are often ramped up in the early years of production. These restrictions are handled in the same way as the other production constraints. Finally, a fairly smooth production campaign is usually desirable. This means that large swings in yearly production quantities cannot be permitted. So limits must be placed on the quantities such that the procurement quantity for a system in one year must not vary from the previous year's quantity by more than some allowable percentage. This percentage is specified as input data to the optimization program. Note that cost analysis estimates are made with respect to a particular production facility, and departures from the specified set of facilities would result in the need to reevaluate the program. Note also that when the sponsor specifies the program with respect to both the quantities and the years of procurement, both the upper and lower production

limits are set to the given yearly quantity values, ensuring that quantities procured match the sponsor's decision. The total quantity to be procured must match the force structure requirement values or infeasibility will result.

For this study the optimization module was not used do to the analysis required by the sponsor.

2.6 Resources

- ❑ Vector-In-Commander (TRAC-FLVN), Corps Level combat simulation.
- ❑ Continued funding for the contractor to perform combat simulation support to model scenarios.
- ❑ CEAC/CAA cost data support.

Figure 15. Resources

Resources from outside of the Center for Army Analysis that were required to conduct VAA are listed in Figure 15. Without these resources this study would not have been accomplished in the allotted time. By receiving the scenario, model and data from the TRADOC Analysis Center, Fort Leavenworth, we saved approximately one year of time/effort. This enabled the quick turn-around of analysis.

Northrop Grumman provided a team that set up and conducted all the VIC runs. They also played a major role in conducting the analysis for this project.

Cost estimates for each system were provided by the Army Cost and Economic Analysis Center (CEAC).

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3 SUMMARY AND CONCLUSIONS

3.1 Summary and Conclusions

The use of Value Added Analysis provides decision makers at the Department of Army level with a tool to quickly evaluate programming and budgeting decisions in the area of system modernization.

Initial findings for this study determined that all the modern systems were in some way more effective then their base counterpart. There was only one significant interaction between two systems – HIMARS and JLENS.

Value Added Analysis provides rigorous analysis that supports the Army's modernization system. It has limitations, mainly that it does not cover all systems. VAA provides insights into modernization issues and provides viable, defendable options useable by the Army leadership as another tool in their decision making process.

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APPENDIX A PROJECT CONTRIBUTORS

1. PROJECT TEAM

a. Project Director:

LTC John Gregory Heck, Resource Analysis Division

b. Team Members:

c. Other Contributors:

2. PRODUCT REVIEWERS

Dr. Ralph E. Johnson, Quality Assurance

3. **EXTERNAL CONTRIBUTORS (If any)**

Northrop Grumman Information Technology

Mr. Sean Vessey, United States Army Cost and Economic Analysis Center (CEAC)

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APPENDIX B REQUEST FOR ANALYTICAL SUPPORT

PART 1

Performing Division: RA ***Account Number:*** **2003012**

Acronym: **VAAFY03** ***Mode (Contract-Yes/No):*** In-house

Title: Value Added Analysis -- Fiscal Year 2003

Start Date: 23-Sep-02 ***Estimated Completion Date:*** 30-Apr-03

Requestor/Sponsor (i.e., DCSOPS): DCS-G8 ***Sponsor Division:*** FDA

Resource Estimates: ***a. Estimated PSM:*** 12 ***b. Estimated Funds:*** $0.00

c. Models to be Used: **VIC & VAA optimizer**

Description/Abstract:
Provide decision makers an analytical approach for the evaluation and prioritization of competing alternatives to support the development of a balanced and effective Army research, development, and acquisition (RDA) program. Analyze different modernization alternatives for the POM and compare them to a baseline of Army systems with respect to cost, effectiveness, and other measures using a third corps-level scenario received from the TRADOC Analysis Center.

Study Director/POC Signature: Phone#: 703-806-5474
Study Director/POC: **LTC John G. Heck**

PART 2

Background:
Headquarters, Department of the Army (HQDA) requires analysis to support the development of a balanced and effective modernization program. Value Added Analysis (VAA) analyzes benefits and costs among different weapon systems and munitions.

Scope: Third scenario using Vector-In-Commander corps-level combat simulation for the combat effectiveness module.

Issues: Selecting appropriate weapon systems for analysis; identifying relevant measures of effectiveness; determining optimal investments strategies.

Milestones: Completion of combat effectiveness, cost, and optimization modules.

Signatures ***Division Chief Signature: Date:*** **Signed and Dated**

Division Chief Concurrence: **Signed and Dated**

Sponsor Signature: **Signed and Dated**

Sponsor Concurrence (COL/DA Div Chief/GO/SES) : **Signed and Dated**

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GLOSSARY

ABBREVIATIONS, ACRONYMS, AND SHORT TERMS

ATACMS	Army Tactical Missile System
BLOS	Beyond Line-Of-Sight
CAA	Center for Army Analysis
CEAC	U.S. Army Cost and Economic Analysis Center
DOE	Design of Experiments
DPICM	Dual-Purpose Improved Conventional Munitions
FCS MGV	Future Combat System Manned Ground Vehicle
FER	Fractional Exchange Ratio
GMLRS	Guided Multiple Launch Rocket System
HE	High Explosive
HIMARS	High Mobility Artillery Rocket System
JLENS	Joint Land Cruise Missile Defense Elevated Netted Sensors System
LER	Lost Exchange Ratio
M1A2Sep	M1A2 Abrams Main Battle Tank Systems Enhanced Package
MLRS	Multiple Launch Rocket System
MOE	Measure Of Effectiveness
NEA	North East Asia
NLOS C	Non-Line-Of-Sight Cannon
OMA	Operations & Maintenance, Army
PGMM	Precision Guided Mortar Munition
POL	Petroleum, Oil, Lubricants
POM	Program Objective Memorandum
RDA	Research, Development, Acquisition
RDT&E	Research, Development, Test, and Evaluation
SWA	South West Asia
TAHA	Tanks, Anti-tank vehicles, Helicopters, Artillery
TRAC	TRADOC Analysis Center

TRAC FLVN	TRADOC Analysis Center Fort Leavenworth
TRADOC	Training And Doctrine Command
UAV	Unmanned Aerial Vehicle
VAA	Value Added Analysis
VIC	Vector In Commander

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